

# Information Dynamics

A Fresh Look at Information  
Its Properties and Implications

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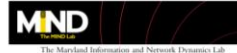


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What **Information** does  
this picture carry ?

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Is it same as what it  
would have been before  
Sept 11 ?



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What **Information** does  
this sequence carry ?

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What is the basic nature  
of Information?

**Only Sentient entities  
handle it!**

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## What is Information ?

- Information is **different** from its representation !!

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- Can have many representations
  - Are they equivalent??



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## Information

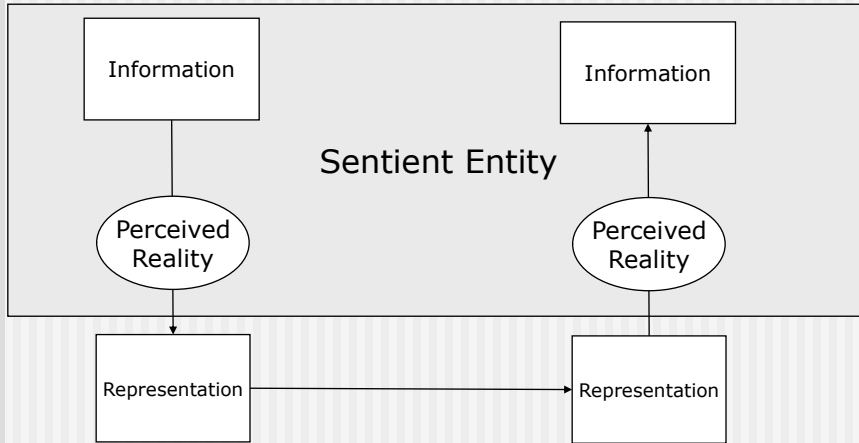
- Many forms
  - Technical – Shannon
  - Everyday use**
- Distinction between information and Representation



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# Information and Representation



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# Information versus its Representation

- No one-to-one mapping
- Representation is meaningless without a relation to the appropriate **contextual** information
- Must understand the relationship of the representation to the appropriate information
- Representations are transmitted across boundaries via physical means (messaging, voices, etc.)
- All typical manipulations of information are through manipulations of its representation
- How is the mapping carried out?



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## Perceived Reality

- All a sentient entity knows...
  - Facts
  - Figures
  - Relationships
  - Models
  - ...
- ...about
  - The environment
  - another entity or system
  - Itself



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## Perceived Reality

- Any local node maintains its view of the universe and other entities in the form of *Perceived Reality*
- Perceived reality is based on
  - Prior **Model** of the Universe and Other Entities
  - Explicit information received and processed
    - Explicit information is processed to integrate it with the perceived reality
    - This integration is based on the model of the universe
    - Information may change the model
- All actions are initiated using the knowledge of the perceived reality
- *All systems have been bootstrapped with information to start its "life"*



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## Models

- Abstraction of an entity or a system.
- Contains properties and relationships **believed** to be true.
- One part of an entity's perceived reality is that of another entity.
- Constantly refined by information:
  - New, Refuting, Removing, ...



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## Perceived Reality

- When a message is received
  - Its contents are converted into information based on the current perceived reality
  - That information is assimilated into the current perceived reality
- A message (representation) can not be converted into information unless the perceived reality contains the means for reverse mapping
  - Language – Symbols - ...



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# What is Information ?

- *Information Entity*
- Information has many
  - **interrelationships**
    - attributes
    - properties
- Interrelationships are information also
- Such interrelationships exist whether they are enumerated/identified or not



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# Information and Representation

- From Information to Representation:
  - Some facts will not be retained!
  - Loss of relationships!
- Manipulation:
  - Informational
  - Representational

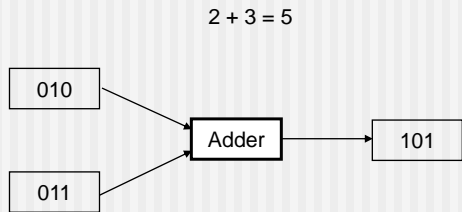


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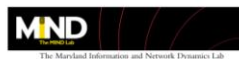


# What is Information ?

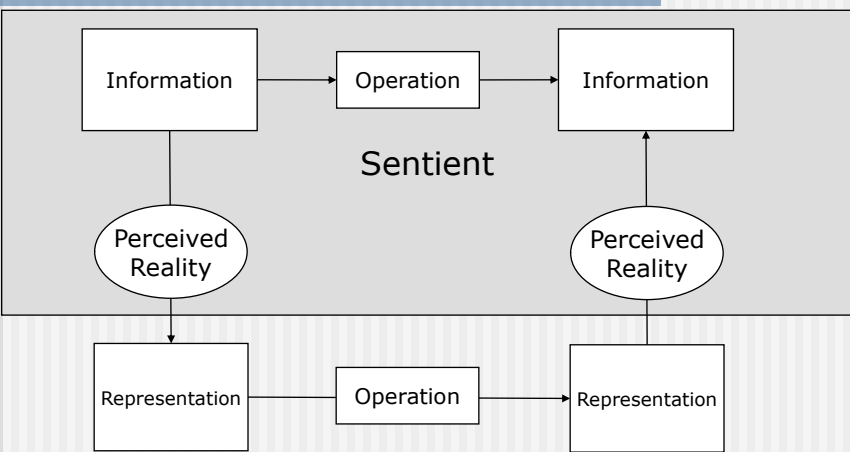
- Information is handled by Sentient Entities
- Its representations can be handled by machines
- Machines only manipulate representations of information.



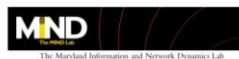
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# Information and Representation



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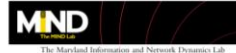
## What Is Information ?

- It is a property /description/characteristics of something
- That something may be another piece of information
  - An object – Physical, logical, virtual,conceptual – group
  - An action
  - A trigger
  - A relationship
- Significance of Information is its interrelationships
  - May be direct or indirect
  - Exist whether enumerated or not
  - May be static or dynamic

Typically retain only small amount of information considered relevant in any system



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## Nature of Information

- Quantifiable
  - Only in the context
    - Temperature in this room
      - Scale
      - Accuracy
      - Time it was recorded
      - Who took it
      - What instrument was used - precision
- Non-quantifiable
  - Most of the information we deal with is of this type



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# Information Representation

- Representations are essential to store, move, or process information
- Capture only some aspects/views/projections of information –
  - A good system designer carries other aspects in her head.
- Example: Data Structure
  - Contains not only representation of some quantities but also of some relationships



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# Information Representation

- Use – Requires associating meaning to it
  - Meaning can only be assigned in context
- Context
  - Integer between 50 and 100
  - Represents temperature in this room in degrees F.
- If both sides understand the context
  - Only need representation of integer number
- If not
  - Common understanding may be English
  - Include description along with the temperature value



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# Information Representation

- Algorithm
  - Sequence of steps
    - Have common understanding of elemental steps
    - Depend on the way they are expressed
      - Machine instructions
      - Higher level language
      - Pseudocode
      - ...



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# Explicit and Implicit Information

- Explicit
  - Conveyed explicitly through messages etc.
- Implicit
  - Derived from explicit and the current knowledge of its relationships - **perceived reality- models**
  - Requires **processing**
    - Spending Resources: Time and Energy
  - **Can be different for different agents !!**



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# Meta-Information

- Ontology
- Levels of Meta Information?



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# What can we do with information

Using Information requires **ACTION**

- Create/capture
- Store
- Move/Retrieve
- Use
  - To derive implicit information – making it explicit
  - To determine some other action to be taken (Choice)
  - To activate a physical operation (output)



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## Storage of information

- In order to store any information which is explicit we need a **representation** for it
- In order to use it as information we need to retrieve it from storage
- A representation of information suitable for storage may not retain many interrelationships.
  - On retrieving
    - some may be recalculated
    - some may be lost forever
    - In particular – information relating to **time** will be lost unless time stamping is done
- Storing/Retrieving of Information are actions

Note that any and all actions generate lot more information than can be captured



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## Movement of information

- Only explicit (represented) information can be moved from one location to the other
- Information to be moved must be in a representation which is understood
  - and can be interpreted by the sender and the receiver.
- The understanding can come from explicitly represented agreements ( which in turn require conventions - **Protocols**)
- It must be storable
- Requires an action



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# Information movement infrastructure

- Network
  - Provides the ability to move info from location  $x$  to  $y$
  - Who initiates the move
    - When
    - Why
- How does  $y$  know that  $x$  has some information it needs?
- How does  $x$  know that  $y$  needs that information?
  
- Knowledge about where what information is?
  - Search Engines !!
    - Have to know where the search engine is and how to access it.

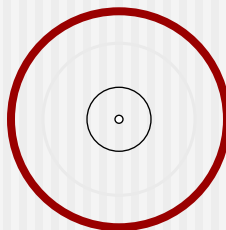


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# Implications of Information Movement

- Moving information from location  $x$  to location  $y$  takes time  $t_{xy}$
- At  $y$  we can only get information from  $x$  which is at least  $t_{xy}$  old



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# Information Uncertainty Principle-1

- The perceived reality at any location **CAN NOT** be the same as the actual reality at any remote location of the global reality
  - Due to the transmission and processing delays
- It is not sufficient to receive the information
  - It must be interpreted and processed to integrate it with the current perceived reality
- Perceived reality at a location may be **consistent** with global/remote reality but can not be the **same**
- We can never have a complete model of another entity:
  - **models abstract knowledge**



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# Information Uncertainty Principle - 2

- Due to finite precision of measurement and representations we can never have complete and precise knowledge of any quantifiable information
- We deal with this uncertainty all the time !!!



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## Value of Information

- Implicit understanding of the value
- Is entity/agent specific
- Use in selecting – deciding among options for processing and taking action
- Value of information changes with time
  - Different for each agent
  - Depends on his perceived reality
  - Can not assign a fixed ordinal scale to the value



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## Value of Information

- Value may be captured by uncertainty models
- Example – queue length at a router
  - The knowledge of the queue length at time  $t$  may be precise
  - The knowledge at a later time given the value at  $t$  will have a variance which will increase with time
  - When we want to know the value of queue length from some other location, the information movement delay increases the variance



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# Information Fusion

Given Multiple observations –

- How to integrate them into one “view”
- One view may contain multiple options / likely scenarios



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# Capture of Information

- Two mechanisms
  - Observation –
    - Through direct or indirect observation/ monitoring/measurement
  - Processing of info – **Make implicit information explicit**
    - To enumerate interrelationships
    - To make deductions
    - To make inductions
    - Using models
- Example: Mathematics
  - A set of interrelationships with a description of when they apply
  - A framework for deductions and inductions to add to the information base
  - Analytical Results => defined interrelationships and descriptions of applicability



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# Action

- Physical Action
    - Results in physical manipulation
  - Non- Physical
    - Thinking
      - Exploring inter-relationships
    - Processing within a computer
- All Actions take **time** and consume **energy**
  - Begins with an information **trigger!**
  - Usually done with respect to an event.



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# Action

- Requires Processing
- Starts under the control of "Trigger"
- Needs
  - Processor
    - Possibly other resources
    - For some time
  - At a location
  - Information as input
- Outcome
  - Additional Information
    - Explicit from Implicit
  - Trigger(s)
  - Storage
  - Movement
  - Physical results
    - Commands to actuators



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## Three Levels

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- Information
- Represented Information
- Physical



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## Types of Actions

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- Make implicit information explicit
- Carry out interpretation/storage/movement of information
- Carry out a physical action by issuing a command to a physical processor
- Transform some information into some trigger which is used to control some later action



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## Trigger

- Required for carrying out an action at a particular time/under some conditions
- Defines
  - What action, where, using what resources, at what time or under what conditions (priority, precedence etc.)
- Based on information/location/time/value
- Requires processing to convert information into a Trigger
- When relationships are fixed – hardwired design – Design time Trigger
- When relationships are dynamic trigger has to reflect it



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## Large Complex System

- A collection of N entities capable of carrying out certain operations
- Has a mission
- Physical resources which can carry out the actions
  - At various locations
- Mechanism for moving information (communication)
- **Design Carried out at Information Level**



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# Coordination: A Distributed System

- **Information-centric view**
- Many interacting autonomous agents
  - Who needs what information at what time
    - Why
    - How will he use it
  - Who has that information at what time
  - How to get the right information at the right place at the right time
- Most algorithms – mechanisms for such movement of information with respect to elemental processing capabilities assumed



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# Role of Time

- Do we need a global/universal clock?
- What type of time is appropriate for Information Dynamics?
  - Absolute Time with a Counter (though it has a value relative to a starting point)
  - Relative Time through Causality



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## Consistency

- How can coordination take place without consistency of models each entity has from one another?
- Models between communicating entities must be consistent and accurate enough
- Who has the responsibility to fix broken models?
- Do models follow a set of rules?
  - Logically, relationally, or operationally.



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## Awareness

- In order for entity A to be aware of entity B, entity A must have a model of entity B.
- Entity B need not have a model of entity A.
- Being aware does not mean having complete knowledge of another.



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## Levels of Abstraction

- Any massively complex system has to be viewed at an appropriate level of complexity
  - Information with **right** degree of detail
  - Only relationships of **interest** and their connections of interest are retained



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## Planning

- Requires knowledge about future
  - Using Models
  - Estimates
    - Accuracy
    - Confidence
- Knowledge of Dynamics
  - Expected changes over time



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## Example – Mutual Exclusion Problem

- N Agents - Cooperative
- Any agent can enter its CS if nobody else is in its CS
- Check if anybody is in its CS
  - If not – enter
  - If yes – wait and try again
- Each action takes time
  - State of agents can change in that time

Entry

CS

Exit

Non – CS

LOOP



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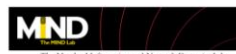


## Mutual Exclusion Problem

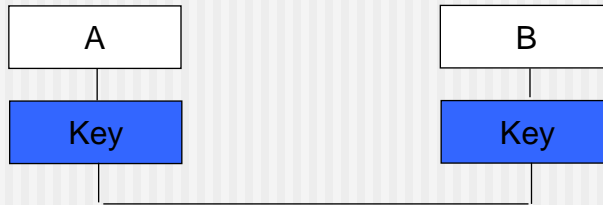
- How to know the state of all other agents
  - Shared memory model
  - Distributed –
    - through messages
- Shared Memory Model
  - Set up a mechanism for sharing of state information
    - Semaphore
  - Delay
    - Atomic action
  - Define checking mechanism
- Distributed
  - Messages
- Algorithms vary in terms of the implications of messages and their meaning
- Simplest – Ask everybody for permission and enter when received from everybody
- How to process a permission request?



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## Example - Security



- Key – part of “perceived reality”
- How does B know which key to use?
- Public Key encryption



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## Example – Link State Routing

- Each node measures delays
- Periodically send the measured delay to every other node
- Determine route as the minimum delay path from source to destination
- Need delay when packet gets there not what it was
- Estimate of future delay rapidly moves towards the steady state values
- IF Steady State values are known
  - Reduce communication
  - Improve routing
- **Demonstrated through implementation/simulation**



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## Information-centric Design

- Having right information at the right place at the right time
- Explicitly take into account the time dependent aspect of information
- Explicitly take into account the value of information
- Explicitly take into account implicit information
- Organize/design system based on the dynamics of information requirements



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## Rover Technology

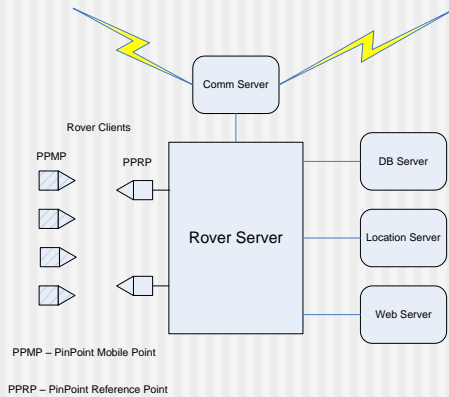
- Context-aware computing platform
  - Location
  - Time
- Self-describing Information Representations
- Services/actions depend on context



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# Rover Technology



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# Rover Technology

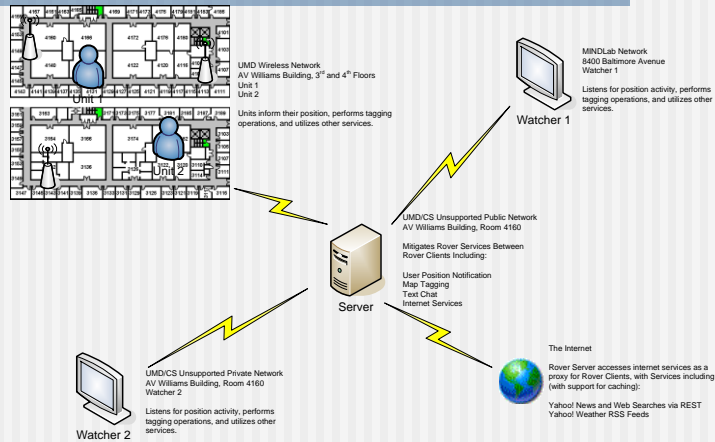
- Designed to address issues in
  - Enterprise Applications
  - Command and Control Applications
  - Pervasive Computing
  - Sensor Networks
  - ...



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# Rover Network Diagram



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# Uses of Information Dynamics

- Framework for
  - Approaching system designs
  - System Analysis
    - Given a design determine
      - All Information Dynamics – Explicit and Implicit
      - Decision Structure
      - Actions
  - System Synthesis
    - Outcome required
      - Processing/Action needed
      - Information needed



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# Questions???

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